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A Model for Calculating Cost of Equipment Downtime and Lack of Availability in Directorates of Engineering and Housing

by
Michael J. Fuerst
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Costs that arise when a vehicle or an item of equipment fails are either tangible costs or consequential costs. Tangible costs (labor and materials) are fairly easy to assess using normal cost accounting. In contrast, consequential costs (those that arise because a vehicle failed, which affects the organization) cannot be assessed with any degree of certainty except under very rigid and well defined circumstances. Installation Directorates of Engineering and Housing (DEHs) need to be able to quantify the consequential costs of equipment failure and include them in equipment decisions.

This research developed a model and method for quantifying consequential costs of equipment downtime that is tailored to the DEH on Army installations.

This model quantifies lack of availability and downtime costs in four categories: (1) Associated Resource Impact costs, arising when failure in one machine affects the productivity and cost-effectiveness of other machines, (2) Lack of Readiness costs, penalty costs assessed against an idle resource, (3) Service Level Impact costs, arising when one machine in the pool of resources fails causing other machines to work extra, and (4) Alternate Method Impact costs, resulting when failure causes a change in the method of operations. Implementation and further development of the model are recommended.

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FOREWORD

This research was conducted for the U. S. Army Engineering and Housing Support Center (USAEHSC), Directorate of Facilities Engineering, Buildings and Pavements Division, Installation Support Branch, under Project 4A162734AT41, "Military Facilities Engineering Technology," Work Unit CG9, "DEH Equipment Maintenance Management System." The USAEHSC technical monitor is Mr. Walter Seip, CEHSC-FB-I.

The work was performed by Dr. Michael C. Vorster and Dr. Jesus M. De La Garza of the Construction Engineering and Management Division in the Department of Civil Engineering at Virginia Polytechnic Institute and State University, Blacksburg, VA, under contract DACA88-88-C-0008 from the Facility Systems Division (FS), U.S. Army Construction Engineering Research Laboratory (USACERL). The authors would like to acknowledge the participation of Mr. Carroll Sheppard, Mr. Bill Vaughn, and Mr. Vance Mitchell at Fort Lee, VA, and Ms. Sara Mahood and Mr. Karl Wolfe at Fort Meade, MD. Mr. Don Hicks was the USACERL Principal Investigator and Mr. Michael Fuerst was the Associate Investigator. Dr. Michael O'Connor is Chief, USACERL-FS. The technical editor was Gloria Wienke, USACERL Information Management Office.

COL Everett R. Thomas is Commander and Director of USACERL, and Dr. L.R. Shaffer is Technical Director.

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1 INTRODUCTION

Background

The costs that arise when a vehicle or an item of equipment fails can be divided into two broad categories: *tangible costs* of labor, materials, and other resources needed to repair the machine; and intangible or *consequential costs* that arise because the vehicle failed, which affects the organization as a whole. Tangible costs are fairly easy to record and estimate using normal cost accounting methods. In contrast, consequential costs cannot be assessed with any degree of certainty except under very rigid and well defined circumstances. However, installation Directorates of Engineering and Housing (DEHs) need to be able to quantify the consequential costs of equipment failure and include them in equipment decisions.

The basic tradeoff in equipment management lies between capital costs and operating inferiority where the latter is defined to include both the direct costs of repair and the consequential costs arising from the failure.[1]

The annual cost of interruption caused by component failure has been defined as the product of the annual frequency, the average duration of a failure, and the downtime cost per unit.[2] This definition is suited to situations where the equipment working on a particular task is configured as a single rigid system and where failure in one component causes the whole system to go down.

Consequential costs have also been assigned to a particular year of equipment life on the basis of an estimated percentage of downtime multiplied by the planned hours of operation for the machine and the hourly cost of a replacement or rental machine.[3] This approach focuses on the failed machine alone and disregards any effect the failure may have on the system as a whole.

A middle course between these approaches defines consequential costs as the product of the hourly cost of the resources affected by a failure, the time necessary to react to a failure, and the frequency of failure.[4] This approach relies heavily on the frequency of failure. It was modified in 1987 to define consequential costs as being dependent on a *failure cost profile* reflecting both the environment within which the machine operates and the manner in which the situation changes as the failure duration increases.[5]

The progression from a simple, rigid, almost dogmatic approach to a profile-based approach to calculating downtime costs reflects a growing concern for the problem of quantifying consequential costs.

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[1] G. Terborgh, "Dynamic Equipment Policy: A MAPI Study," *Machinery and Allied Products Institute and Council for Technological Advancement* (1949), p 27.

[2] E. A. Cox, "Equipment Economics," *Handbook of Heavy Construction*, 2nd ed., J. A. Havers and F. W. Stubbs, Jr., Eds. (McGraw-Hill, 1971), pp 7-15.

[3] S. W. Nunnally, *Managing Construction Equipment* (Prentice-Hall, 1977), p 226.

[4] M. C. Vorster, "A Systems Approach to the Management of Civil Engineering Construction Equipment" (Ph.D. in Engineering research thesis, University of Stellenbosch, South Africa, June 1980), p 238.

[5] M. C. Vorster and G. A. Sears, "A Model for Retiring, Replacing or Reassigning Construction Equipment," *Journal of Construction Engineering and Management*, Vol 113, No. 1 (March 1987), pp 125-37.

Any approach is inherently subjective. However, a methodology to assess the dollar value of consequential costs can bring some rigor to aspects of equipment management that remain subjective despite advances in recording and processing data pertaining to tangible costs.

Quantifying consequential costs with a reasonable degree of accuracy can influence equipment decisionmaking in three ways. First, consequential costs can be considered alone as a measure of the organizational impact of the equipment's imperfect performance. This criterion can be used to compare one machine with another and to identify members of a fleet that merit special attention. Consequential costs can also be used to assess the effectiveness of maintenance policies and procedures. Effective maintenance operations should keep the *mechanical quality* of equipment at a high level, thereby ensuring that consequential costs remain low. The balance between maintenance expenditures and consequential costs is thus a good measure of maintenance effectiveness. Finally, consequential costs can be an input to an economic replacement model. Adding them to normal owning and operating costs gives a more complete assessment of economic life. Consequential costs can add helpful information to economic life studies because they illustrate that neither costs nor economic life are independent of the consequential effects of downtime and lack of availability.

Objective

The objective of this research is to develop a model for quantifying consequential costs of equipment downtime that is tailored to the DEH on Army installations.

Approach

A comprehensive literature review was undertaken to help define the state of the art in quantifying costs. Several papers referred to the concept of consequential costs but did not address cost quantification in specific terms. Articles of interest, but not necessarily of direct relevance, are listed as Uncited References. The literature search revealed that the failure cost profile methodology (discussed in the Vorster and Sears article) was of greatest potential use in achieving the objective of this research.

Discussions with DEH personnel and their clients at Fort Meade, MD, and Fort Lee, VA, provided insight into the size and complexity of the fleets deployed at each installation as well as the operational demands placed on each category of equipment and vehicles. The site visits led to the review of the model structure.

Mode of Technology Transfer

The algorithms described in this report will be incorporated into a computer program that will allow DEH organizations to realistically evaluate the consequential costs of equipment failures and unavailability. The program will be available from the U.S. Army Construction Engineering Research Laboratory (USACERL), Facility Systems Division, P.O. Box 4005, Champaign, IL 61824-4005. Researchers at USACERL are also developing a fleet management expert that will use these algorithms to help the DEHs make equipment repair and replacement decisions.

2 DEH FLEETS AND LAD COSTS

Lack of Availability and Downtime (LAD) costs occur when a machine breaks down during use and is unable to meet expected performance. These costs can rarely be measured, recorded, or allocated using standard costing systems. The quantification of LAD costs is thus an estimating process, and any model used for this process is a tool to help managers estimate the LAD costs for a particular machine in a particular time period.

Estimating tools rely on the processes of grouping work items and classifying costs to streamline procedures. The model developed in this research is no exception. It requires:

1. Classifying a fleet into *LAD groups* according to the type and main application of the vehicles and equipment involved,

2. Describing the task being performed when a failure occurs by articulating a number of possible failure *scenarios* for each LAD group, and

3. Classifying LAD costs into *categories* that reflect the effects likely to result under certain circumstances.

The role of LAD groups, scenarios, and LAD cost categories as a framework for estimating LAD costs is depicted in Figure 1.

LAD Groups

The fleets of vehicles and equipment used to support engineering operations on Army installations are both large and complex. Individual *units* vary from small lawn mowers and other grounds maintenance equipment to large cranes and earthmoving equipment.

To quantify LAD costs, DEH equipment is classified into LAD groups. A LAD group is defined as a given set of machines or vehicles that:

1. Work on the same set of tasks and thus incur the same types of LAD costs when failure occurs, or

2. Work on each task in a given set of tasks for the same proportion of their total available time.

It is probable that machines in a given LAD group will perform a variety of tasks (loaders can load trucks, blend material, and do general cleanup work), and that different amounts of time will be allocated to each task.

A LAD group might include:

1. All of an installation's dump trucks of similar size or productivity that are deployed to carry out a given set of tasks,

2. All of an installation's trucks used as mobile supply and resource vehicles for a given trade doing maintenance and service tasks, or

3. All of an installation's fire trucks.

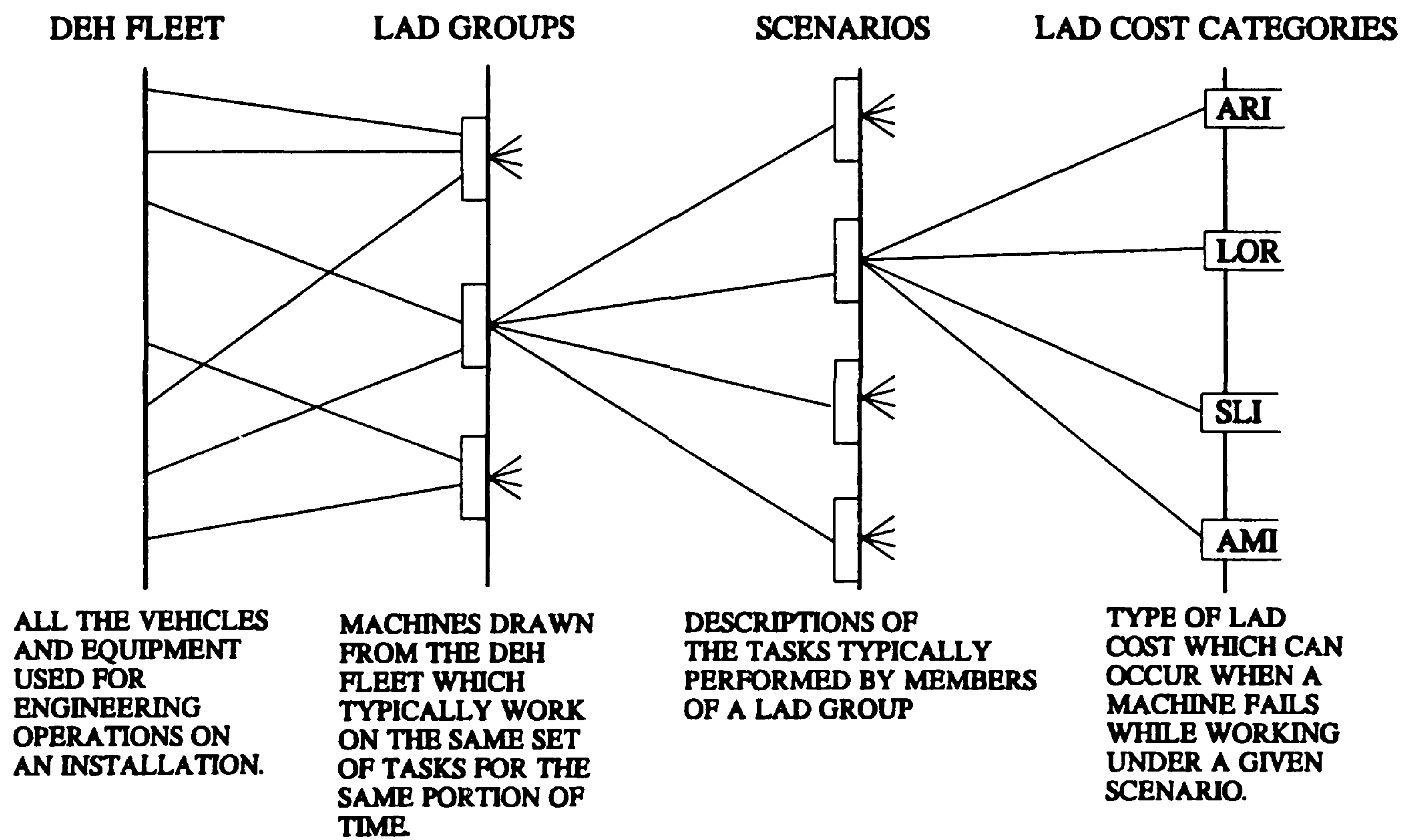

Figure 1. The relationship between the DEH fleet, LAD groups, scenarios, and LAD cost categories.

As with any classification system, defining LAD groups requires striking a balance between a large number of small, finely-tuned groups and a smaller number of groups whose membership may not be precisely similar.

Scenarios

The ability to estimate LAD costs depends on the ability to describe what is likely to happen when a failure occurs. Scenarios must be articulated to describe the task and what happens when a member of a given LAD group breaks down. The scenarios will facilitate analysis and provide a static background that the cost effects of the described failure can be assessed against.

The equipment and vehicles in a LAD group frequently perform more than one task, and frequently fail under different circumstances. Thus, more than one failure scenario may apply to a given LAD group. The percentage of time spent or work done by members of a LAD group under a given scenario may need to be assessed. A weighting factor can then be developed to apply to each scenario so LAD costs can be weighted and added later.

It must be emphasized that the scenarios do not play a role in computing LAD costs and serve only to provide a predefined description of a situation as a background for the estimating process.

LAD Cost Categories

Providing a mechanism to estimate the cost of the various possible effects in a given scenario requires defining several LAD cost categories. Initially, project researchers envisioned only two classifications. More classifications were developed after the site visits. The classifications finally adopted were:

1. Associated Resource Impact (ARI) Costs. ARI costs arise from the effect of a unit's failure on the productivity of associated resources and/or units. They usually occur shortly after the failure, are directly related to the failure that just occurred, and are proportional to the number of failures. For example, a driver loses productive time when a truck breaks down, and a mechanic's scheduled work is disrupted to attend to a failure. ARI costs also include those costs that occur when a failure in one machine affects the productivity of another. Loss in productivity of a truck when a loader fails, and loss in productivity of a loader when one of the trucks it is loading fails are additional examples of ARI costs.

2. Lack of Readiness (LOR) Costs. LOR costs are penalty costs assessed when an item that should be constantly available is not. Fire trucks and ambulances are examples of such items. Because this cost is assessed whenever the item is unavailable, regardless of whether it is actually in demand, it motivates personnel to keep equipment on the ready line.

3. Service Level Impact (SLI) Costs. SLI costs relate to groups of similar vehicles that form a common pool of resources needed to perform a certain service. SLI costs result when one or more vehicles in the pool breaks down and thereby depletes the pool to the extent that the other vehicles must work in a more costly manner so that resources are available to maintain a specified operational demand. Downtime on one of three refuse trucks, which causes the other two to work overtime to maintain the service level, is an example of SLI costs.

4. Alternate Method Impact (AMI) Costs. AMI costs occur when the failure and continuing downtime of a given machine forces a change from an optimum to less than optimum method and thereby causes the organization to incur additional cost. For example, AMI costs result when a loader and trucks

are used in place of a more efficient, but failed, motor scraper, and when standard vehicles, rather than customized, more efficient vehicles are used to collect refuse. AMI costs usually occur only after an extended period of downtime and frequently involve specific expenditures associated with mobilizing and demobilizing the resources needed for the alternate method.

Machines in a given LAD group working under a given scenario are unlikely to incur LAD costs under all four LAD cost categories. ARI costs are very likely to occur in every instance to reflect, at least, the impact of the failure on the driver or operator. LOR costs occur if some sort of penalty should apply when a productive resource is unable to respond to an operational demand regardless of whether it is actually needed. Whether SLI or AMI costs occur depends on the characteristics of the LAD group and the scenario under consideration.

3 THE LAD COST MODEL

The LAD Cost Model is an estimating tool designed to help estimate the LAD costs over a given time period for a particular machine and for a LAD group as a whole. The definition of LAD groups, the description of the scenarios, and the input parameters needed to estimate each LAD cost category create an estimating environment that draws on data unique to a particular machine and on the operating conditions unique to each DEH. The model can be implemented on a microcomputer using any of several popular programmable database products. As in most computer programs, successful implementation relies on the ability of programmers to create an intuitive environment for users.

This chapter describes the data necessary to support the model, and the algorithms for calculating LAD costs from this data.

LAD Group and Equipment Item Information Requirements

LAD Group Definitions

Each LAD group is described as follows:

1. An identifying code (no more than 5 characters) and/or

2. An optional longer description (50 characters should suffice).

Equipment Item Definitions

Equipment items are defined and assigned to each LAD group. Each equipment item is described by:

1. An identifying code such as a serial number or license plate number.

2. Any optional information to enhance the description such as make, manufacturer, or year. This data is not essential to operation of the model and would be used solely to enhance outputs and reports.

3. The LAD group to which the item belongs.

Equipment Item Performance Data

Data describing each item's previous or projected future performance will include:

W_i = number of hours the i^{th} item is in use during the study period

D_i = number of hours during the study period the i^{th} item is unavailable due to breakdowns

V_i = number of times the i^{th} item breaks down during the study period.

The study period dictates the model's output. If the in-use hours, hours unavailable due to breakdown, and number of breakdowns reflect values for some previous time period, the output from the model evaluates the LAD costs for that time period. If these items are projections for some future time period, then the model's output predicts LAD costs for that future period.

Scenario Descriptions

Each LAD group requires one or more scenarios (i.e., tasks) under which its items operate. The data items describing each scenario are (1) an identifying code, (2) an optional textual description, and (3) the percentage of operating time spent on the task by each member of the LAD group. A logical extension of the model would allow each item to have its own percentage assignments among its LAD group's scenario.

Each scenario requires entering cost estimating parameters for one or more of the four LAD cost classifications (Associated Resource Impacts, Lack of Readiness, Service Level Impact, and Alternate Method Impact). The classifications are discussed in the following sections.

Associated Resource Impact (ARI) Costs

ARI costs arise from the effect of the unit's failure on the productivity of associated resources and/or units. The parameters for calculating ARI costs apply to a given LAD group working under a given scenario. ARI costs for a particular machine in the LAD group are calculated from performance data unique to the machine and the ARI parameters for the machine's LAD group.

ARI costs have been defined as costs that occur as a direct result of a failure. Figure 2 shows the accumulation of ARI costs along a time line stretching from the point where the failure occurs and normal operations cease (C) to the point where normal operations resume (R). Each associated resource is affected differently by a failure and thus will have its own:

1. *Impact lag* (profile CL in Figure 2). This is the period from the time of the failure to the start of the impact on the resource. For certain types of resources, such as the driver of a failed truck, this lag period will be very short. For other resources, this lag will be relatively long, as when a bulldozer fails and affects a loader that is loading material stockpiled by the bulldozer.

2. *Impact duration* (profile CD in Figure 2). This is the time from the failure to the end of the impact on the resource. The impact duration can be equal to the total duration of the impact (CR) if replanning is not possible. On the other hand, the impact duration will be substantially shorter if resources can be reassigned during the period affected by the failure.

3. *Impact period* (profile LD in Figure 2). This is the time during which ARI costs accumulate.

4. *Cumulative cost profile* (profile LMNO in Figure 2). This defines how the accumulated impact cost on an associated resource grows as the impact period increases. The profile LMNO in Figure 2 shows that an impact of duration LD yields a cost of \$Y(d).

The cost accumulation curve depends on the number of associated resources affected during each portion of the impact period, and the extent to which they are affected. Thus, for the associated resources, the cost per hour per associated resource when working, the cost per hour per associated resource when idle, and the number of resources affected are all required. Once these are specified, the program completes a table or screen similar to Figure 3.

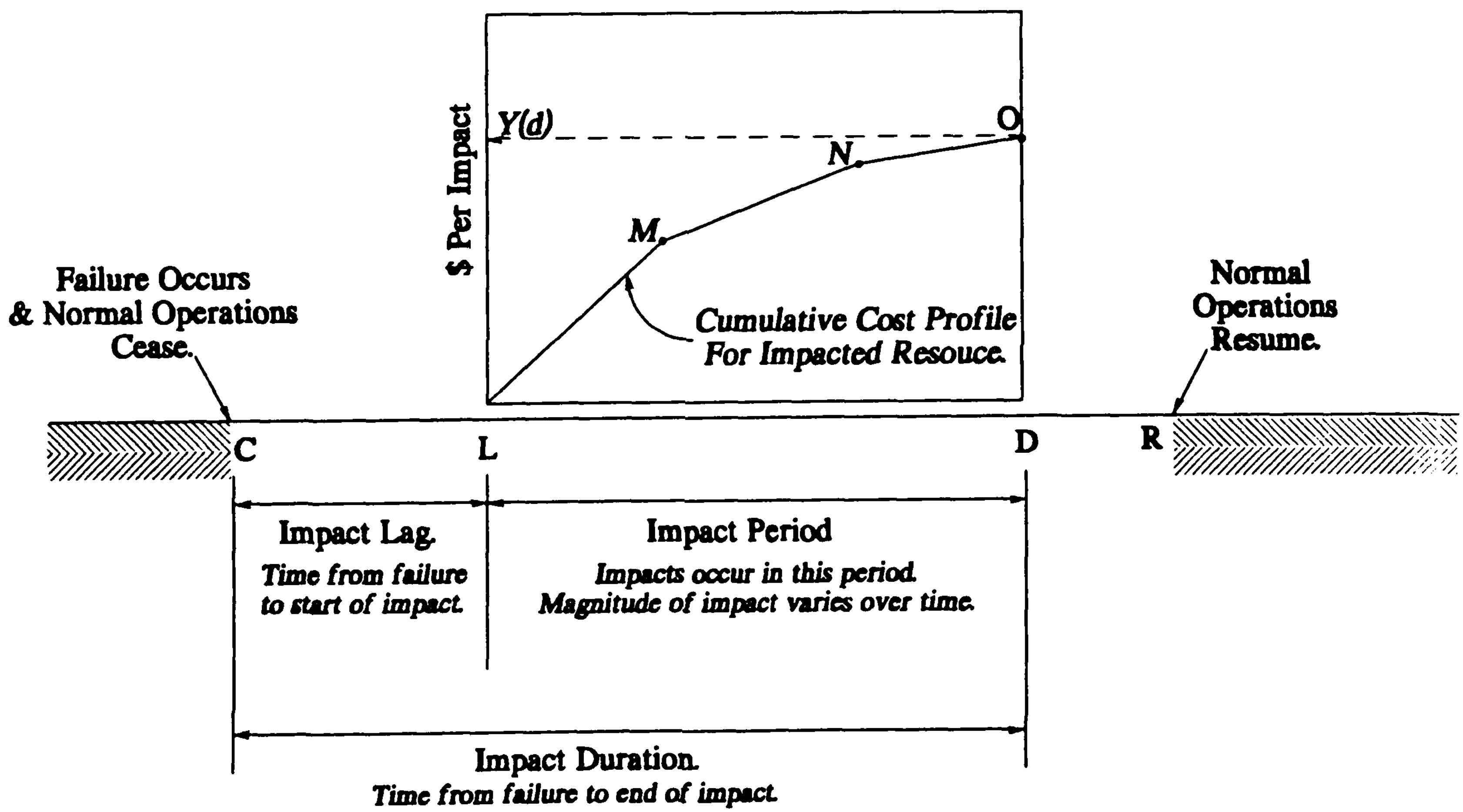

Figure 2. Time line illustrating occurrence of ARI costs.

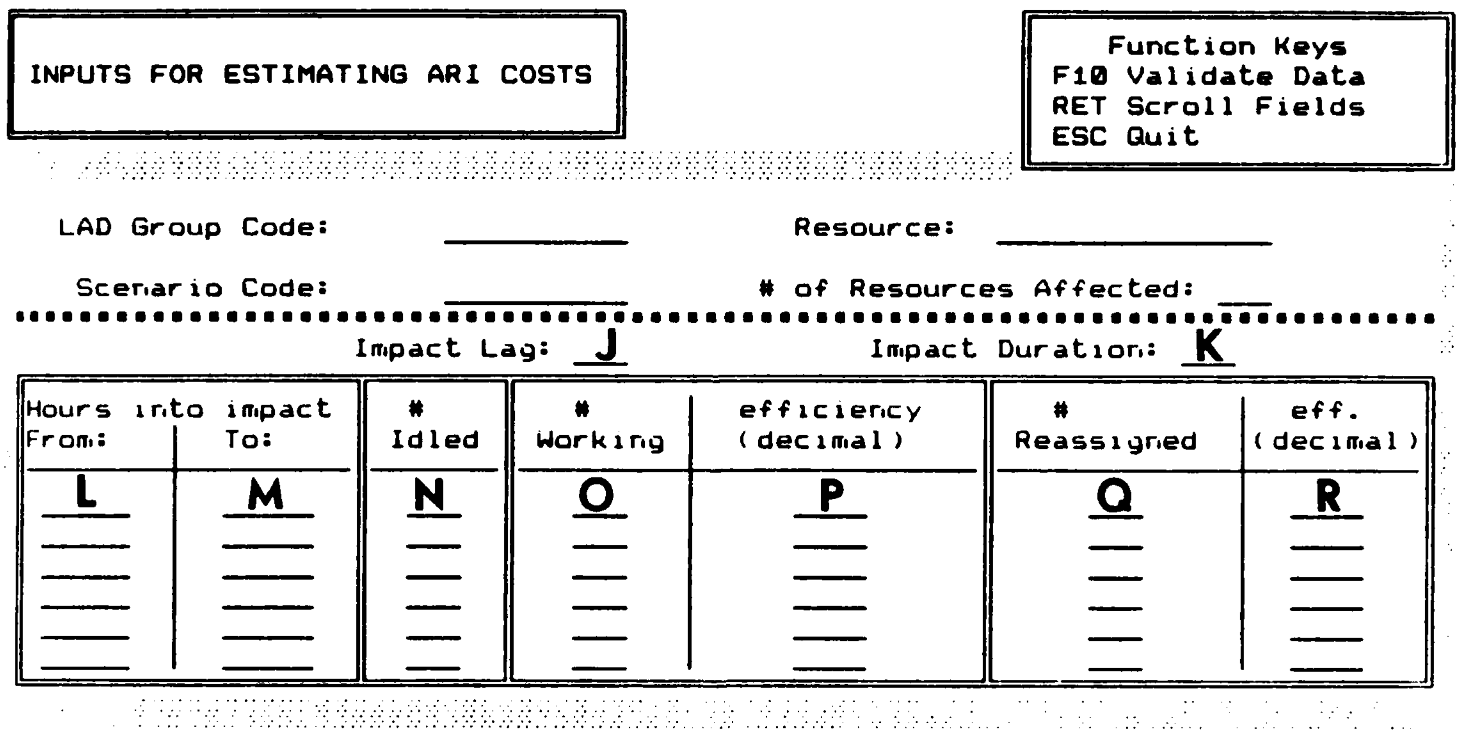

Figure 3. Input parameters for estimating ARI costs.

The answers to two questions help establish the impact duration.

1. Will replanning eliminate the impact of failure on this resource within the day, if failure occurs early enough within the day?

In this case, an estimate of the impact lag and the impact period (or duration) is required. The cumulative cost profile covers the period from the start to the end of the estimated impact period. In this situation, the capability exists to bring in a replacement for the failed item relatively quickly. The expected ARI cost for a failure under this scenario is calculated by assuming that the failure is equally likely to occur at any hour of the workday.

If the answer to this question is no, then the next question to ask is:

2. *Will the impact of the failure on this resource terminate at the end of the day?*

If yes, normal operations can be resumed at the start of the next working day. In this case, the cumulative cost profile starts at the end of any impact lag and continues to the end of the workday. The expected ARI cost for a failure under this scenario also assumes that the failure is equally likely to occur at any hour of the workday.

If the answer to this question is no, then the effects of the failure can last beyond the end of the workday. The following workday estimates are required:

- the impact lag,
- the most optimistic duration (i.e., the shortest it will ever be), designated t_1,
- the most likely duration, designated t_2, and
- the most pessimistic duration (i.e., the longest it will ever be), designated t_3.

The three estimates for the duration are used to calculate the parameters of a generalized beta distribution.[6] Normalize the three estimates with the equation:

$$u_i = (t_i - t_1)/(t_3 - t_1) \Rightarrow u_i = o_j \quad u_3 = 1 \qquad \text{[Eq 1]}$$

Use these normalized estimates to calculate estimates for the mean (μ) and variance (σ^2) of the resulting beta distribution for the normalized variables:

$$\mu = (u_1 + 4u_2 + u_3)/6 \qquad \text{[Eq 2]}$$

$$\sigma^2 = [(u_3 - u_1)/6]^2 \Rightarrow \sigma^2 = 1/36 \qquad \text{[Eq 3]}$$

(These estimates of the mean and variance of the beta distribution, used in most PERT applications, imply an assumption that the standard deviation is one-sixth of the range between the maximum and minimum durations.[7])

[6] G. J. Hahn and S. S. Shapiro, *Statistical Models in Engineering* (John Wiley and Sons, 1967), pp 91-96.

[7] J. M. Antill and R. W. Woodland, *Critical Path Methods in Construction Practice*, 3rd ed. (John Wiley and Sons, 1982), pp 301-02; L. A. Swanson and Harold Pazer, *PERTSIM Test and Simulation* (International Textbook Company, 1969) p 11.

Calculate the parameters of the the beta distribution for the normalized variables:

$$\alpha = \frac{(1-\mu)[\mu(1-\mu)-\sigma^2]}{\sigma^2} \quad \text{[Eq 4]}$$

$$\beta = \frac{\mu\alpha}{1-\mu} \quad \text{[Eq 5]}$$

Numerically integrating the product of the resulting generalized beta distribution with the cumulative cost profile produces the expected ARI costs for a single failure of an item for the subject LAD group. Multiplying the cost of a single failure by the number of failures for an item produces the ARI cost for the item of the LAD group during the study period. Note that other distributions can be used if available information dictates.

Lack of Readiness (LOR) Costs

LOR costs are penalty costs assessed for an equipment item, typically emergency equipment, not available for service. The penalty charges start accumulating after an impact lag (which may be zero). Figure 4 illustrates this. The failure occurs at Point C; CL represents the impact lag; CD represents the impact duration; and penalties accumulate during LD, the impact period. The cumulative cost profile is fairly straightforward in that LOR costs relate only to machines in the LAD group under study and have nothing to do with any other resources. The profile starts at point L and has a uniform slope proportional to a penalty cost per hour that reflects the losses arising from the inability of a productive asset to respond to operational demands.

Since the cumulative cost profile is linear, the following formula can be used to calculate the LOR_i costs for the i^{th} item over a given time period:

$$LOR_i = P \times [(D_i - (V_i \times H)] \quad \text{[Eq 6]}$$

where
- P = lack of readiness penalty cost in \$/hour
- D_i = number of hours during the study period the i^{th} item is unavailable due to breakdowns
- V_i = number of times the i^{th} item breaks down during the study period
- H = impact lag in hours.

Service Level Impact (SLI) Costs

SLI costs occur when, in a pool of similar vehicles performing a certain service, lack of reliability in one or more pool members causes the others to work in a more costly manner to maintain the required level of service. The common pool of resources from which a certain level of service is demanded corresponds to a LAD group. When quantifying SLI costs for one member of the group, consider:

1. The number of vehicles needed to satisfy operational demands under normal conditions,

2. The probability that a certain number of vehicles will be available in any single day given the overall availability of each member in the LAD group, and

3. The costs of the actions taken to ensure that the service level is maintained when the number in service falls below that required to satisfy operational demands.

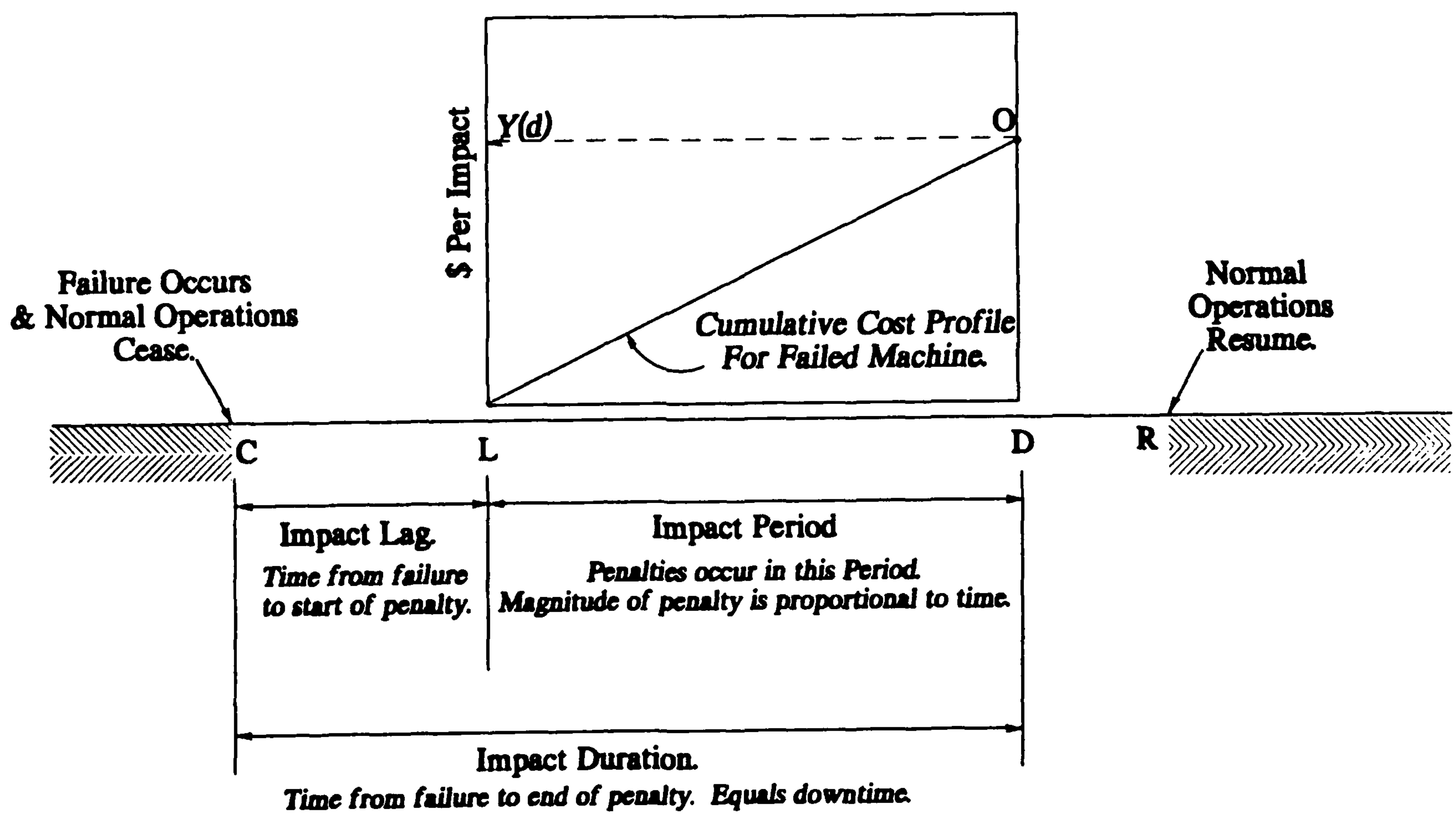

Figure 4. Time line to illustrate occurrence of LOR costs.

This analytically complex problem is best addressed with a Monte Carlo situation model, which operates as follows:

The number of equipment items in the LAD group, n, is known from the LAD group and equipment item definitions. Other items that must be input are:

- the number of items, m, required to maintain normal service, and
- the cost per day, c_x, if only x > n-m items are down.

A downtime ratio, Z_i, for each of the n members of the LAD group (i = 1, 2, . . ., n) is calculated using the formula

$$Z_i = \frac{D_i}{(D_i + W_i)} \qquad \text{[Eq 7]}$$

where D_i = number of hours during the study period the i^{th} item is unavailable due to breakdowns
W_i = number of hours the i^{th} item is in use during the analysis period.

Both D_i and W_i are given for each group member.

The downtime ratios of the individual machines in the LAD group are used to simulate two results:

1. P(x), the probability of having x = 1 . . . n items in the LAD group down and incapable of working in any day; and

2. P(i|x), the conditional probability that item i is down, given that x items are down that day. For example, P(2|4) = .4 means that when four items are down, item 2 will be down 40 percent of the time. In other words, when four items are down, 40 percent of item 2 is down. The sum of the P(i|x) over i for a given x equals x.

The expected SLI cost for item i on a day when x items are down is

$$SLI_{ix} = \frac{c_x \, P(i|x)}{x} \qquad \text{[Eq 8]}$$

The expected daily SLI cost for item i is therefore given by

$$SLI_i = \Sigma \, SLI_{ix} \, P(x) \qquad \text{[Eq 9]}$$

Alternate Method Impact (AMI) Costs

AMI costs result when the failure and continuing downtime of an item in a LAD group forces a change in the method used to carry out the work described in the scenario. The change is assumed to be from an optimal to a less than optimal method. Thus, the organization suffers a consequential

cost proportional to the cost differential between the methods and the quantity of work done under the less favorable circumstances.

Figure 5 illustrates the accumulation of AMI costs. C and R represent the points where normal operations cease and resume; CL shows the time lag from the time of failure to, in this case, the time of introduction of the alternate method; and CD shows the impact duration. The cumulative cost profile is essentially the same as that for the LOR cost module, except for the following characteristics of the cumulative cost profile:

• A vertical step (LM) appears initially to reflect the setup costs associated with mobilizing the new method.

• The slope of the profile in the range M to N is proportional to the cost and production differential between the methods.

• A second vertical step (NO) is included at the end to reflect the cost of breaking down or demobilizing the new method.

In practice, the mobilization and demobilization of an alternate method occur only for severe failures. Thus, a *mobilization percentage* is used to reflect the proportion of failures relative to all failures for which mobilization and demobilization occur.

The linear nature of the cumulative cost profile between M and N and the use of a mobilization percentage makes it possible to calculate AMI costs for item i as follows:

$$AMI_i = S \times Q \times (D_i - (L \times V_i)) + V_i \times Mp\,(Mz + Dz) \qquad \text{[Eq 10]}$$

where AMI_i = Alternative Method Impact Costs for item i in the study period
S = cost surcharge in \$/unit caused by the alternative method
D_i = number of hours during the study period the i^{th} item is unavailable due to breakdowns
Q = quantity produced in units per hour by the alternative method
V_i = number of times the i^{th} item breaks down during the study period
H = impact lag in hours
Mp = mobilization percentage
Mz = cost of mobilization
Dz = cost of demobilization.

Because the model provides the mechanisms needed to quantify several forms of consequential costs, it can model various situations. However, it is complex. Accuracy beyond a certain level can be attained only through disproportionate amounts of complexity, as Figure 6 illustrates. In developing the model, every increase in complexity has been checked to ensure that it produces a meaningful and relevant improvement in potential accuracy.

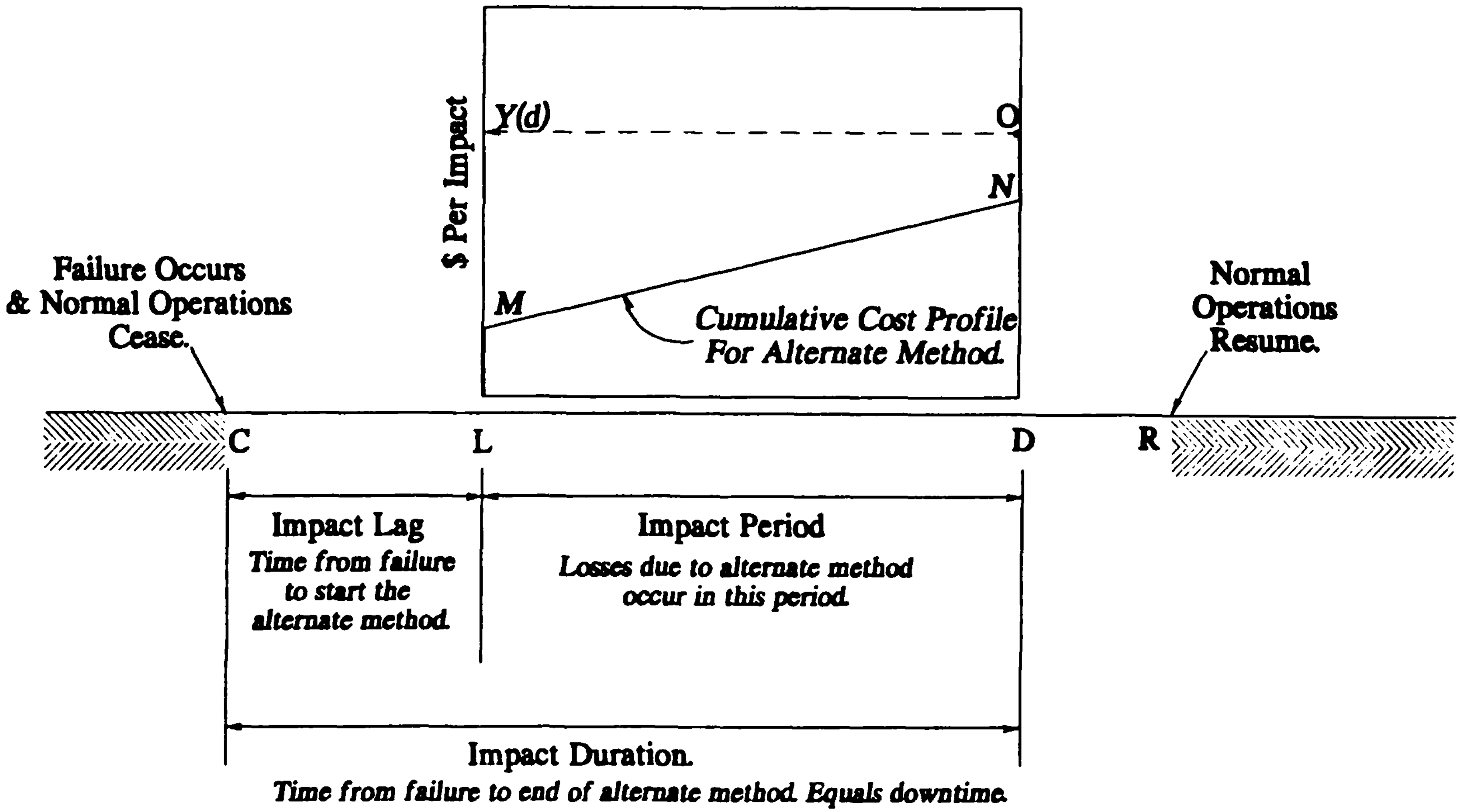

Figure 5. Time line to illustrate occurrence of AMI costs.

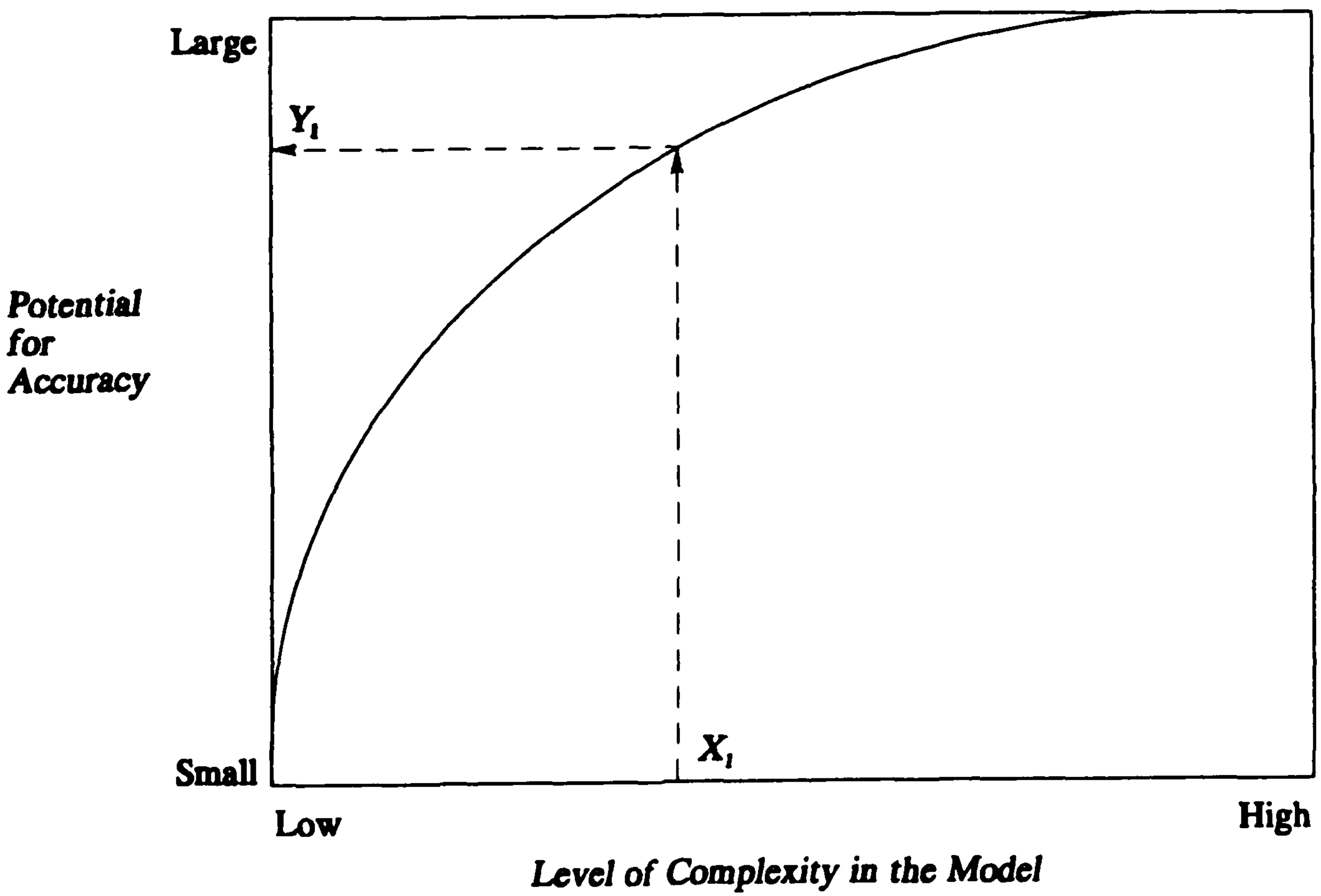

Figure 6. Relationship between complexity and the potential for accuracy.

Discussion regarding the level of complexity of the model must be blended with discussion regarding the level at which the complexity in the model is implemented in the field. Three possible implementation strategies are:

• Implementation in breadth where certain parameters are neglected and LAD costs are estimated for a large portion of a fleet by implementing the model at a low level of complexity.

• Implementation in depth where a high level of accuracy is required in a relatively small portion of the fleet.

• Total implementation at a high level of detail for all or most of the fleet.

The model can accommodate any of the above three implementation strategies. Choice of strategy depends on the use and value of the information the model can produce, the ability to quantify the required estimating parameters, and the availability of the monthly data. Figure 7 illustrates possible strategies.

The estimating parameters required for each LAD cost category and each scenario appear numerous and complex. Quantifying the value for each parameter must be done in consultation with the individual or organization affected by the impact on the scenario. Repetition and practice will help, but remember that the whole concept of consequential cost is not amenable to exact solution.

The complexity of the input parameters and the overall structure of the model has resulted in limiting the monthly data requirements to three elements:

V = number of times a machine breaks down and disrupts planned operations in a month
D = number of hours a machine is broken down and unable to respond to operational demands in a month
W = number of hours a machine works during a month.

Although these requirements are not numerous, monthly data must be available in order to implement the model.

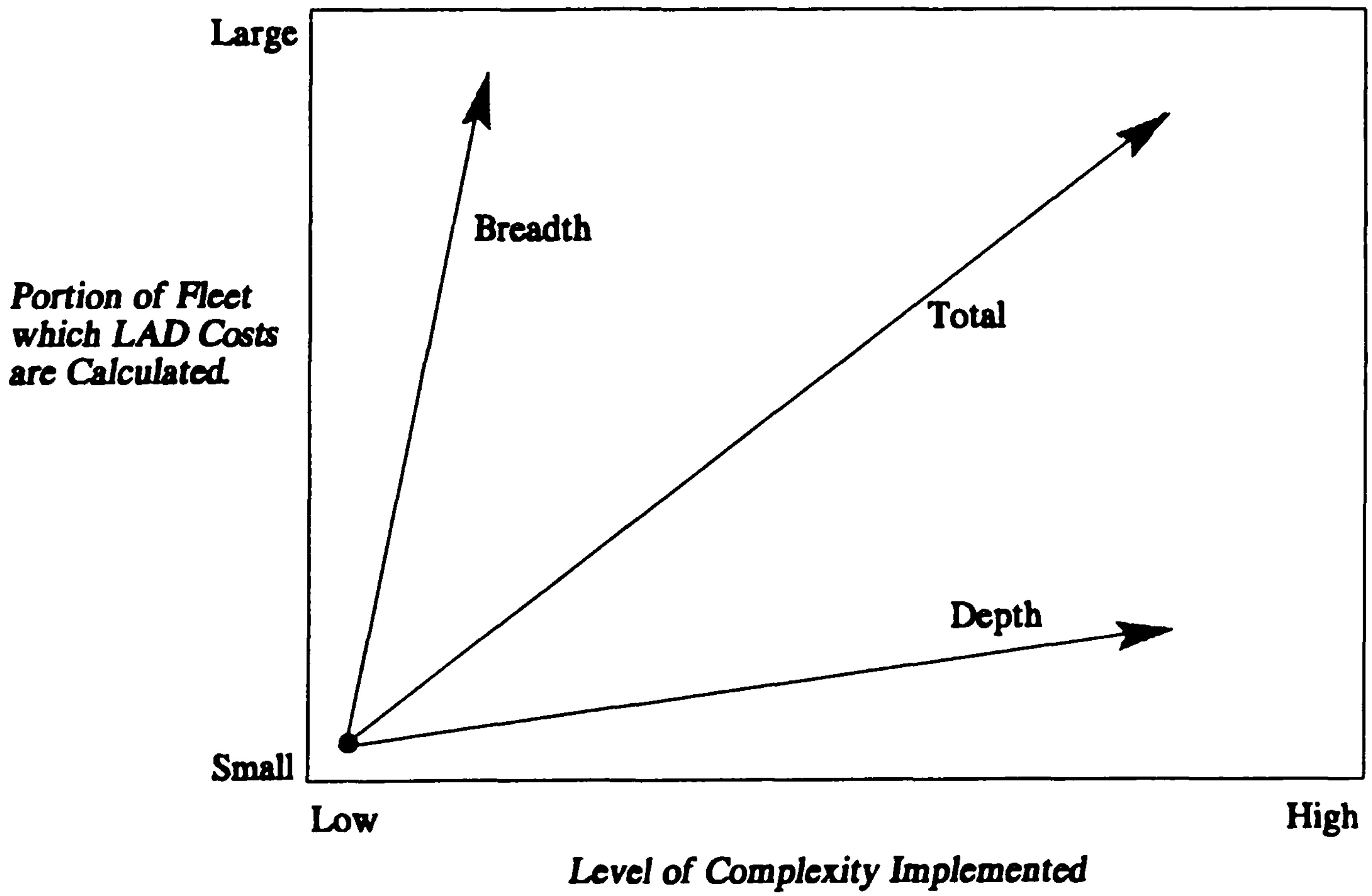

Figure 7. Implementation strategy.

4 SUMMARY AND RECOMMENDATIONS

The LAD Cost Model developed during this research is a tool designed to help the DEH estimate consequential costs over a given time period for a particular machine and for a LAD Group as a whole. It also represents a significant step toward the rational quantification of consequential costs by proposing several forms of consequential costs and quantifying the consequential costs associated with lack of availability and downtime in a particular operating environment.

A computer program is being written to enable users to easily input the large number of parameters and estimates. The model should be field-tested under controlled conditions and modified in response to user reactions.

Eventually, the model should be integrated with an equipment management database system. Integration will allow automatic entry of unit descriptions and actual failure durations, an integrated report-generating capability, and most important, consideration of LAD information in deciding when to replace equipment.

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